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Decreasing Stress Through a Spatial Audio and Immersive 3D Environment: A Pilot Study With Implications for Clinical and Medical Settings

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Abstract

There is evidence that music-based interventions can be effective in treating clinical and non-clinical populations. With the emergence of audio-visual technologies, there are new opportunities for developing web-based applications that have therapeutic effects in mental health and medical settings. Here we conducted a pilot study ($N = 100$) to test if an immersive web-based spatial audio application can decrease stress and negative mood states. Results showed that the application was effective for both clinical ($n = 40$) and non-clinical ($n = 60$) groups, and that the effect was most profound for individuals diagnosed with depression and anxiety disorders. Though the present study needs to be replicated with physiological methods, the findings provide initial evidence that web-based spatial audio applications can be effective for short-term stress reduction and have the potential to be a supplement to clinical music interventions, but not a replacement or substitute for such interventions.

Keywords

Anxiety, depression, music, spatial audio, stress

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Music has been used as a therapeutic tool since antiquity (Blacking, 1995). Research from the past several decades has provided evidence that music-based interventions are effective in treating symptoms for several clinical and non-clinical populations (Porter et al., 2017; Whipple, 2004; Zhang et al., 2016; Zhao et al., 2016). Specifically, music has been shown to be effective in the context of clinical music therapy,[1] and in the area of music and medicine.[2]

In terms of clinical music therapy, one-on-one and group treatments can increase attention and concentration (Kim et al., 2008), improve communication and social skills for autistic individuals (Whipple, 2004), and decrease symptoms of distress for individuals with depression and post-traumatic stress disorder (PTSD) (Aalbers et al., 2017; Bensimon et al., 2008; Carr et al., 2012; Zhao et al., 2016). In the context of music and medicine, a meta-analysis showed that listening to soothing music before and after surgical procedures can increase recovery rates (Hole et al., 2015).

However, clinical music therapy is not always accessible, particularly in medical settings. Geographic, transportation, and financial factors, and the high demand for practitioners, may prevent individuals from receiving the treatment they need, and may leave many without care. For example, there are over 130,000 inpatient surgeries performed each day in the United States (Centers for Disease

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Control and Prevention, https://www.cdc.gov/nchs/data/nhds/4procedures/2010pro4_numberprocedureage.pdf), but there are only 7,000 clinical music therapists in the United States (Certification Board for Music Therapists (CBMT), https://www.cbmt.org). This leaves medical doctors and nurses (who are not trained in clinical music therapy) responsible for providing ad-hoc music interventions that are likely based on their intuition instead of research evidence. For example, a medical doctor may make an uninformed and non-evidenced suggestion that a patient listen to a specific type of music to decrease anxiety before a surgery. However, depending on the attributes of the music that is suggested, it may be ineffective or, even worse, have an unintended negative effect. For example, previous research on analgesia has shown that music perceived as low in arousal (slow tempo and relaxing attributes) and with high depth (emotional and cerebral attributes), can reduce pain (Basinski et al., 2018). But one the other hand, music that is high in arousal and considered to be aggressive can produce negative effects such as aggression in the short term (Fischer & Greitemeyer, 2006).

With the development of music-based applications, evidence-based approaches can be used as a supplement between sessions with a board-certified practitioner or therapist. Furthermore, with the development of spatialized audio and virtual reality experiences, the recreation of real-world music listening can be more accurately achieved. For example, spatialized audio is a surround-sound and dimensional approach that provides an audio experience that mimics the way people hear music in real life. Since web-based platforms are often designed by industry-based companies rather than scientific laboratories, there is a need to empirically test the outcomes of these applications. Though previous research on spatialized audio and stress response is limited (Kobayashi et al., 2015), there is evidence that music listening in general can improve stress response across different therapeutic and medical contexts (Knight & Rickard, 2001; Nilsson, 2009; Thoma et al., 2013). For example, ambient sounds have emerged to be effective at reducing stress and anxiety (Calcaterra et al., 2014; George et al., 2007; Hartling et al., 2013; Johnson et al., 2012; Reychler et al., 2015).

Separately, there is emergent evidence that virtual reality 3D environments can positively impact mental health and stress response in a variety of settings including occupational therapy and rehabilitation, pediatric populations, and for soldiers suffering from post-traumatic stress (Difede & Hoffman, 2002; Gromala et al., 2015; Piskorz & Czub, 2018; Plante et al., 2006; Rothbaum et al., 2001; Taneja et al., 2017; Tarrant et al., 2018). Here too, research has converged to show that ambient environments (e.g., art and olfactory scents), in addition to ambient music, can have a positive impact on stress reduction (Lehrner et al., 2005; Massimi et al., 2008; Vetter et al., 2015).

We conducted an exploratory pilot study to test a novel web-based application that features spatial audio and an immersive 3D environment and its effectiveness for stress reduction. For the purposes of this pilot, we selected "Prelude" by Composure (henceforth, Prelude), for three primary reasons. First, to our knowledge it is the only application of an immersive and fully-interactive web-based experience for stress reduction. More specifically, it uses spatialized sound with unencumbered design, and invites participants into a virtual space. It combines music with virtual environments to provide a space for a psychological and physiological effect. Second, though there has been no prior scientific research conducted on Prelude, its audio and visual features can be characterized as ambient. Given the prior research discussed about the positive impact that ambient sounds and environments have on stress reduction, this made Prelude an ideal application for our pilot. Third, Prelude is accessible through a web browser and can be used on most devices ranging from mobile phones to virtual reality headsets. This makes it easily accessible, user-friendly, and ideal for online research.

To test the effectiveness of Prelude, we administered it to adult participants online. Our pilot study had three aims: (1) to examine stress levels at baseline and after using Prelude; (2) to examine mood states at baseline and after using Prelude; and (3) to examine the evoked emotions from Prelude and preferences for different aspects of the application.

Methods

Ethical Considerations and Pre-Pilot

Previous research in music and science (e.g., musical preferences) routinely administers audio and visual stimuli-sets successfully online without harming participants (Cleridou & Furnham, 2014; Greenberg et al., 2016, 2020; Rentfrow et al., 2011; Vuoskoski & Eerola, 2017). Typically, this research makes it explicit to participants that they can withdraw or bypass any stimulus if they find it distressing. However, considering the present research was focused on stress and anxiety, we added an extra step of precaution. To ensure that Prelude would not cause distress of any kind to participants, we conducted two pre-pilots.

The first pre-pilot included 20 research assistants and acquaintances of the authors of this article. Prelude was administered to these 20 individuals and they provided verbal feedback about their experience. None of these individuals reported any distress or difficultly of any kind. In the second pre-pilot, five people were recruited through a Facebook advertisement. These five individuals completed all of the measures and the full Prelude experience that would be administered later in the actual pilot. None of the five individuals reported any distress or difficulty via quantitative responses. These two pre-pilots strongly suggested that Prelude and the online survey administrations would not cause any distress or harm to participants. To ensure that there were no issues in the pilot study, we included an

open-ended response question where participants could report any technical issues or difficulty that that they encountered during the survey.

Since we were collecting data about mental health status and about state anxiety, we wanted to ensure participant anonymity and deidentification. Therefore, we administered the study and collected data on the Qualtrics platform, which uses a multitude of precautions to secure its data. A White Paper that details these precautions can be provided on request from the authors or from www.Qualtrics.com. The data that were downloaded from the Qualtrics survey platform was de-identified. The data were stored on password protected hard drives and remained de-identified and anonymized.

Participants

We used the Musical Universe platform (www.musicaluniverse.org) for participant recruitment in the pilot study, (Greenberg & Rentfrow, 2017). Musical Universe is a web platform where people take personality and music-related tests and get feedback on their scores. Users of the Musical Universe learned about the platform from popular media websites including CNN, the BBC, and IFLScience. To date, more than 200,000 people have taken tests on the Musical Universe platform. The Musical Universe database has been used to address research questions in and outside of the music sciences (Fricke et al., 2018; Greenberg et al., 2018, 2020; Warrier et al., 2020). Some of these studies have been about those who provided information about formal clinical diagnoses (e.g., autism). However, in general, the frequency distributions reported showed that the prevalence of diagnoses in participants in the Musical universe database is neither more nor less than that which appears in the general population (Greenberg et al., 2018; Warrier et al., 2020). This consistency is likely because the initial media advertisements for the Musical Universe recruited participants interested in musical preferences and personality, rather than in a more clinical topic like mental health. See below for a discussion about prevalence rates in our pilot study, which used a different advertisement that was more focused about stress.

Several thousand users of the Musical Universe platform volunteered to be part of a participant pool and to volunteer in ongoing research studies. In the summer of 2018, an email advertisement was sent to the entire participant pool without any targeting based on prior demographics or data. The email advertisement stated:

> We are exploring cutting-edge scientific methods to promote well-being using music. In the present online study, you will be asked to fill out several self-report questionnaires on your mood and then to engage in an audio/visual experience called "Prelude" by Composure. Afterwards, you'll have to provide information on your experience. At the end you will receive feedback about the effect of "Prelude" by Composure.

A total of 154 people began the survey. The survey included an open-ended questionnaire where participants were able to indicate any technical difficulties or other difficulties experienced when using Prelude. There were no difficulties indicated by any participants. After multiple screening steps (see section on statistical analysis), 100 participants remained for analysis. Of those who indicated, 59% were women, 39% were men and the sample ranged from 18 to 80 with a mean of 40.17 ($SD = 16.97$). The sample was geographically diverse with 27% from the UK, 16% from the U.S., 15% from Germany, and 6% from Canada. The sample was 77% White, 7% Latino, 4% of mixed ethnicities; 68% indicated that they played a musical instrument with a mean of 3.67 ($SD = 4.42$) years of formal musical training.

Participants completed a consent form before participating (see supplemental material online). The consent form told participants that (1) they must be at least 18 years old to participate; (2) their responses would remain confidential and no personal identifiable information will be shared with other parties; (3) that they were able to withdraw at any time; and (4) that participating should not cause them discomfort of any kind. Participants were also provided with contact information if they had any questions about the research. The use of data was approved by the Ethical & Independent Review Services (#19087-01) (http://www.eandireview.com). We sought ethical approval from an independent review board because the data are owned by Musical Universe, LLC, which is an independent organization and is not affiliated with any university or academic institution. We decided to send an application to the Ethical and Independent Review Services (E&I Review) because E&I Review is an AAHRPP (The Association for the Accreditation of Human Research Protection Programs, Inc.)-accredited private institutional review board used and trusted by some of the largest data and science companies today, including 23andMe, Inc (https://www.23andme.com). There are a multitude of published studies that were given ethical approval by E&I Review (e.g., Warrier et al., 2018). De-identified data for this study is available on the Online Science Framework (https://osf.io/ba5mh/?view_only=7fd867df8baa404781a7ce701a11d8cc).

Procedures

After giving consent to store and use their de-identified data for research purposes, participants were asked to complete a series of questionnaires. Afterwards, they were asked to spend a minimum of 5 minutes in the Prelude experience to allow sufficient engagement (the minimum time was determined by the pre-pilots). After ending the experience at a self-selected time, users indicated the amount of time spent in Prelude and immediately completed the same questionnaires that they had completed at baseline, in addition to several others. In the penultimate stage, participants completed demographic information. At

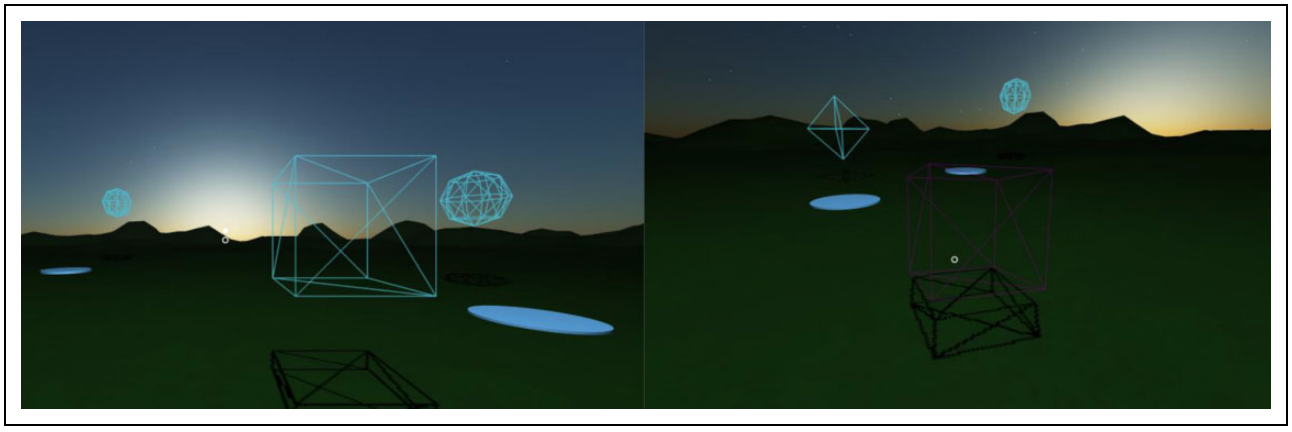

Figure 1. Screenshots from the Prelude experience: (a) initial setup; (b) dragging an element to another place.

the end of the survey, participants were provided with feedback about their scores that included their mood and stress levels before and after the experience. As mentioned above, the email advertisement for the study had informed participants that they would receive feedback about their scores. However, since we did not explicitly mention stress, mood, or specific constructs we were studying, we did not feel we were introducing any biases, but rather were prompting participants to be honest in their responses in order to receive accurate feedback. The procedural instructions and measures presented to participants is included in the supplemental material (available online).

Prelude Design

Visual. In Prelude, the participant begins in a wide-open field at dusk. The sun is going down over a mountain range in the distance while a chorus of chirping crickets is heard just under the swell of soothing music. In the foreground are four transparent geometric shapes floating in space just above the ground with only their vertices highlighted in light blue. Near each floating object are light blue circles on the ground. Participants are able to look around in all directions and notice there is a large Play/Pause icon behind them as well as a Volume adjustment bar. These controls can be clicked by the user to manipulate the music, but not other sounds. Each floating object can be clicked on to play short musical moments that complement the main track, and in doing so those objects gently tumble in place and change their outline color. Additionally, these objects can be selected and moved anywhere in space that the user chooses. Each object's sound then can be heard coming directly from that object in its new location whether it be left, right, above, below, in front, behind, near or far from the user's position. This gives the participant the ability to customize the listening and viewing experience as they like. Furthermore, users can also click on the light blue circles on the ground to "teleport" to that location in 3D space. This simultaneously gives the participant a new visual point of view within the scene, as well as a new listening experience as all of the sounds' relative positions and distances to the user stay true to each new position. This means that the physical location (along the X, Y, Z axis) of each object/sound source remains fixed in that location (unless moved by the user) no matter where the user is in space. Finally, being that it is a self-guided experience, the participant can stay for as short or as long a time as they desire. There is no game to play, nor any objective to meet outside of the user's own desire to enjoy and feel calmer and a greater sense of well-being. **Figure 1** displays two images of the Prelude experience.

Audio. The following descriptions are based on an interview with the creator (also the composer and programmer) of Prelude and describes his motives and interpretations of the music. With a goal of creating an audio-focused experience, the creator composed an original musical piece designed to be calming and soothing. Special attention was paid to steer clear of typical trappings of relaxation music and instead create something more accessible to a wider population of users. He approached the composing duties as if it were a score to a scene in a film. In doing so, specific choices were made in regards to form, structure, instrumentation, and the melodic and harmonic approach. He aimed to create sounds that were heavily atmospheric, free of musical frictions, and with small moments of musical tension to make all other moments feel more satisfying, thus giving the user a sense of journey, of having gone through something and feeling better for it on the other end of the experience. The audio can be characterized as ambient and mellow—it is instrumental with a slow tempo, which corresponds with prior research showing that "soothing" music can decrease stress (Hole et al., 2015).

The creator used judicious use of harmonies based on dominant modalities rather than pentatonic or unaltered major scales. Intervals of a second and other intervals that are typically associated with dissonance are also used occasionally to create moments of tension, but each are soon followed by moments of release through returns to more consonant intervallic relationships in the harmonies and

melodies. In terms of instrumentation, choices were made to combine sounds that felt both familiar and other-worldly at the same time. This is most notably heard in the use of strings and piano with support from synthesizer pads, drones, and bass. Another objective in creating the musical experience was to create the individual "musical moments" that people can interact with by manipulating floating objects in the scene. For this, two factors had to be considered: (1) that each musical moment could be played at any time and still complement the main musical piece; and (2) that their sonic qualities were such that they were easy to localize by the listener's ear. Regarding the latter consideration, each musical moment needed to focus on upper frequencies since our ears can more readily identify where those sounds are coming from in space. Meeting both challenges ensured that participants had the best opportunity to notice and enjoy interactive possibilities and the spatialized audio effect that is central to the experience.

Measures

Prior Measures. Demographic information and data about clinical diagnoses were collected as part of previous research (Fricke et al., 2018; Greenberg et al., 2018; Greenberg & Rentfrow, 2017; Warrier et al., 2020). The diagnostic item in the demographics portion of the questionnaire in the prior research asked, "Please indicate below if you have been diagnosed with any of the following conditions. You can select multiple items." There were 9 answer choices: attention deficit/hyperactivity disorder ($n = 1$); bipolar disorder ($n = 0$); depression ($n = 26$); generalized anxiety disorder (GAD) ($n = 17$); panic disorder ($n = 5$); posttraumatic stress disorder (PTSD) ($n = 6$); seasonal affective disorder (SAD) ($n = 3$); social anxiety disorder ($n = 3$); and autism ($n = 1$). This method of online assessment of clinical diagnoses is used frequently for the purpose of online studies (e.g., Baron-Cohen et al., 2014).

Baseline Measures. Before beginning Prelude, participants provided baseline scores on anxiety, stress, and mood. Participants first completed the widely used 10-item Perceived Stress Scale (PSS) (Cohen et al., 1983) which assesses stress levels over the past month on a scale from 0 (*never*) to 4 (*very often*). To assess for current mood state, participants completed the 24-item Profile of Mood States-Adolescents questionnaire (POMS-A) (Terry et al., 2003), which used a on a scale ranging from 0 (*not at all*) to 4 (*extremely*) to assess six mood states (the POMS-A has been used successfully in adult samples in previous music studies: Vuoskoski & Eerola, 2011). The six factors assessed with the POMS-A are *anger*, *confusion*, *depression*, *fatigue*, *tension*, and *vigor,* with Cronbach's alpha ranging from $\alpha = .67$ (vigor) to $\alpha = 90$ (fatigue). Despite its original development for adolescents, the POMS-A has been shown to be a valid measurement for adult samples as well (Terry et al., 2003). To assess for the current stress state, participants completed the widely used 6-item Spielberger State–Trait Anxiety Inventory (STAI: 6-item) (Marteau & Bekker, 1992).

Post-Measures. Immediately after the Prelude experience, participants indicated the amount of time (in minutes) that they spent in Prelude. Next, participants were presented with the following statement: "Please click next to continue with the questionnaire. Some of the questionnaires are the same or similar to the ones you took previously. However, complete them again based on how you are feeling now." Participants then completed the POMS-A and STAI for a second time. Next, participants were asked a series of questions on their preferences for different features (e.g., audio and visual) of Prelude using a 7-point Likert scale, and to report any difficulties via an open-ended response question. Next, users completed the 25-item Geneva Emotional Music Scales (GEMS) (Zentner et al., 2008) to assess for the evoked emotions felt during the Prelude experience. The GEMS reports emotions on nine scales: *wonder*, *transcendence*, *tenderness*, *nostalgia*, *peacefulness*, *energy*, *joyful activation*, *tension*, and *sadness.* Finally, users provided demographic information including sex, age, ethnicity, country of residence, and clinical diagnoses. All measures are provided in the supplemental material.

Statistical Analysis

Screening. Several steps were taken to screen the 154 participants who began the survey. First, participants who did not complete all measures were removed. Second, participants below the age of 18 years and above the age of 80 were removed to account for age-related hearing differences. Third, participants who spent less than four minutes on Prelude were removed to guarantee a minimum engagement time in the experience. Fourth, participants who reported having technical difficulties were removed. After this four-step procedure, 100 participants remained for analysis.

Allocating Clinical Groups. Clinical groups were determined based on self-reports of clinical diagnoses. As depression and anxiety disorders were selected most frequently and had comorbidities with each other, we decided to make a single clinical group consisting of depression and anxiety disorders (depression, GAD, panic disorder, PTSD, SAD, and social anxiety disorder). Taking into account participants who had comorbid diagnoses, a total of 40 participants were allocated to the depression and anxiety group (henceforth "clinical group"). A total of 60 individuals indicated that they had not been diagnosed with any of the 9 clinical diagnoses presented to them and were allocated to the control group.

Statistical Methods. Changes in scores in baseline and outcome measures were calculated using stepwise linear regression models. For stress levels and mood states, the

Table 1. Linear regression on changes in the STAI before and after Prelude.

	b	*SE*	*t*	p_t	*F*	p_F
Step 1: Intercept only[a]						
Intercept	−30.20	7.33	−4.12	<.001		
Step 2: Level[a]						
Intercept	96.66	18.05	5.36	<.001		
STAI T1	−0.52	0.07	−7.44	<.001		
R^2	.36				55.31	<.001
Step 3: Control variables[b]						
Intercept	82.77	33.32	2.48	.015		
STAI T1	−0.41	0.07	−5.77	<.001		
Age	0.97	0.36	2.74	.007		
Sex	−7.13	10.75	−0.66	.509		
Time in Prelude	−3.40	1.57	−2.17	.033		
Clinical group	−16.90	11.89	−1.42	.159		
R^2	.44				14.41	<.001
ΔR^2	.078				3.21	.016

[a] $N = 100$.
[b] $N = 98$.
STAI: Spielberger State–Trait Anxiety Inventory.

difference between the two time points (baseline and outcome) was calculated for each measure. Next, a one-parameter regression model was used to estimate the intercept to see if the overall change was significantly different from zero (equivalent to a *t*-test). In the second step, the baseline score was inserted as a control variable, as participants with more extreme values are statistically more likely to show larger changes (e.g., through *regression to the mean*). In the third step, control variables (age, sex, the time spent in Prelude, and the clinical group) were inserted to determine if any of these controls has a significant effect on the outcome.

Results

Stress Levels

Changes in stress measured by the STAI-6 showed a decrease in stress in participants from baseline to outcome. The intercept-only model showed a significant mean decrease of $b = 30.20$ ($t(99) = 4.12$, $p < .001$, Cohen's $d = 0.41$). The second step of the regression model showed that a higher stress level before Prelude led to a larger decrease in stress ($b = -.52$, $t(99) = 5.36$, $p < .001$, $R^2 = .361$). Last, the third regression step showed that older participants had a smaller decrease in stress levels than younger participants ($b = .97$), while more time spent in Prelude led to a larger decrease ($b = -3.40$), as shown in **Table 1**. Means and *SD*s for variables are reported in Table S1 in the supplemental material.

Mood States

Changes in mood state were observed with the POMS-A. All mood states experienced significant decreases when testing the intercept: anger ($t(99) = 3.37$, $p < .01$), confusion ($t(99) = 3.36$, $p < .01$), depression ($t(99) = 6.33$, $p < .001$), fatigue ($t(99) = 4.54$, $p < .001$), tension ($t(99) = 5.70$, $p < .001$), and vigor ($t(99) = 3.36$, $p < .001$). In addition, mood levels at baseline were significantly negatively associated with each of the respective differences. None of the control variables had a significant influence on the level of change. Mean changes in mood states are visualized in **Figure 2**.

Evoked Emotions

Since Prelude decreased stress and negative mood states, we next examine which evoked emotions from Prelude may have played a role on its effects. Toward that end, the nine evoked emotion dimensions measured by the GEMS-25 were included in the regression model from the STAI as a fourth step. As seen in **Table 2** and **Figure 3**, regression analysis revealed that peacefulness, tension, and joyful activation contributed significantly to stress reduction above and beyond the other control variables ($R^2 = .727$, $\Delta R^2 = .288$, ps $< .001$),. Pearson product-moment correlations for all variables are reported in Table S2 in the supplemental material. The mean levels of the evoked emotions are presented in **Figure 3**.

Self-Reported Depression and Anxiety Disorders

Results from an independent samples *t*-test showed that the reduction in stress, as measured by the STAI-6 before and after Prelude, was greater for the clinical group than for the control group: $t(98) = 2.93$, $p < .01$, Cohen's $d = 0.58$. To control for sex and age, a regression model was fitted to predict clinical status; the stress reduction as measured with the STAI remained significant ($b = -.002$, $t = 2.58$, $p = .012$), while sex and age did not have predictive power for determining clinical status. In a second regression model, changes in mood states as measured with the POMS-A were examined for predicting clinical status (**Table 3**). Only the change in tension significantly predicted clinical status ($b = -.06$, $t = 2.09$, $p = .040$), suggesting that the clinical group experienced a greater reduction in tension-related moods.

Preferences for Prelude

Participants indicated an overall favorable experience with Prelude ($M = 5.00$, $SD = 1.57$). There was no significant difference between preference ratings for the overall experience with Prelude and the preferences for the music ($p = .22$). However, participants indicated they enjoyed the musical elements of Prelude more than visual elements ($t(99) = 4.73$, $p < .001$).

Discussion

Our pilot study leveraged a novel spatial-audio application and found preliminary evidence for short-term

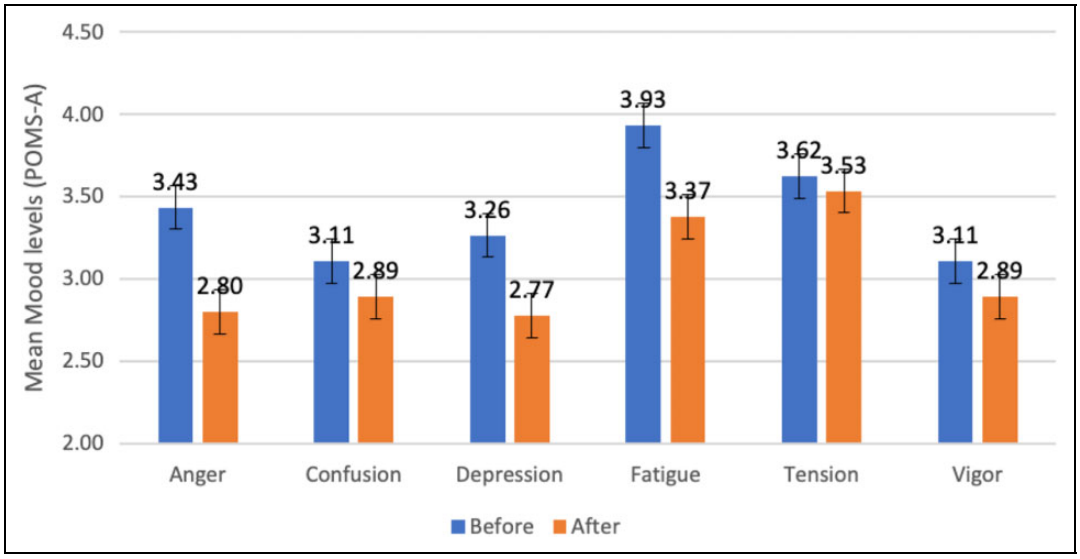

Figure 2. Mean differences in mood before and after Prelude.

Table 2. Effect of evoked emotions on changes in stress level. Continuation from Table 1.

	b	*SE*	*t*	p_t	*F*	p_F
Step 4: Evoked emotions						
Intercept	135.00	28.97	4.66	<.001		
STAI T1	−0.45	0.06	−7.61	<.001		
Age	0.02	0.29	0.08	.937		
Sex	−10.17	8.10	-1.26	.213		
Time in Prelude	2.78	1.44	1.93	.057		
Clinical group	−5.73	9.07	−0.63	.529		
GEMS Wonder	−18.91	9.85	−1.92	.058		
GEMS Transcendence	4.76	11.49	0.41	.680		
GEMS Power	−19.02	10.80	−1.76	.082		
GEMS Tenderness	3.42	9.35	0.37	.716		
GEMS Nostalgia	−1.90	10.27	−0.19	.853		
GEMS Peacefulness	−27.53	6.99	−3.94	<.001		
GEMS Joyful activation	24.09	10.72	2.25	.027		
GEMS Sadness	0.24	9.40	0.03	.979		
GEMS Tension	21.97	8.02	2.74	.008		
R^2	0.73				15.78	<.001
ΔR^2	0.29				9.72	<.001

Note: $N = 98$.
GEMS: Geneva Emotional Music Scales; STAI: Spielberger State–Trait Anxiety Inventory.

improvements in several measures that are considered to reflect wellbeing. Specifically, evidence from self-report assessments showed that Prelude can reduce stress, decrease negative moods, and evoke positive emotions including peacefulness, tenderness, and nostalgia. Furthermore, the application was shown to be effective in participants with self-reported depression and anxiety disorders, and to reduce feelings of anger and stress more substantially in the clinical group than the control group. Together, this provides initial evidence that web-based spatial-audio applications may be suitable to be administered as a supplement to treatment by mental health professionals including psychologists, psychiatrists, and social workers (e.g., between sessions).

Prior theory and research have begun to focus on the role of specific music features (rather than genres or styles) for individuals and groups (Greenberg et al., 2015, 2016). Our findings in this pilot build on prior research that has shown that relaxing and ambient sounds and environments improve stress and anxiety in various clinical and medical contexts, including rehabilitation, pediatrics, soldiers suffering from posttraumatic stress, and in hospitals during pre- and post-operative settings (Calcaterra et al., 2014; Difede & Hoffman, 2002; George et al., 2007; Gromala et al., 2015;

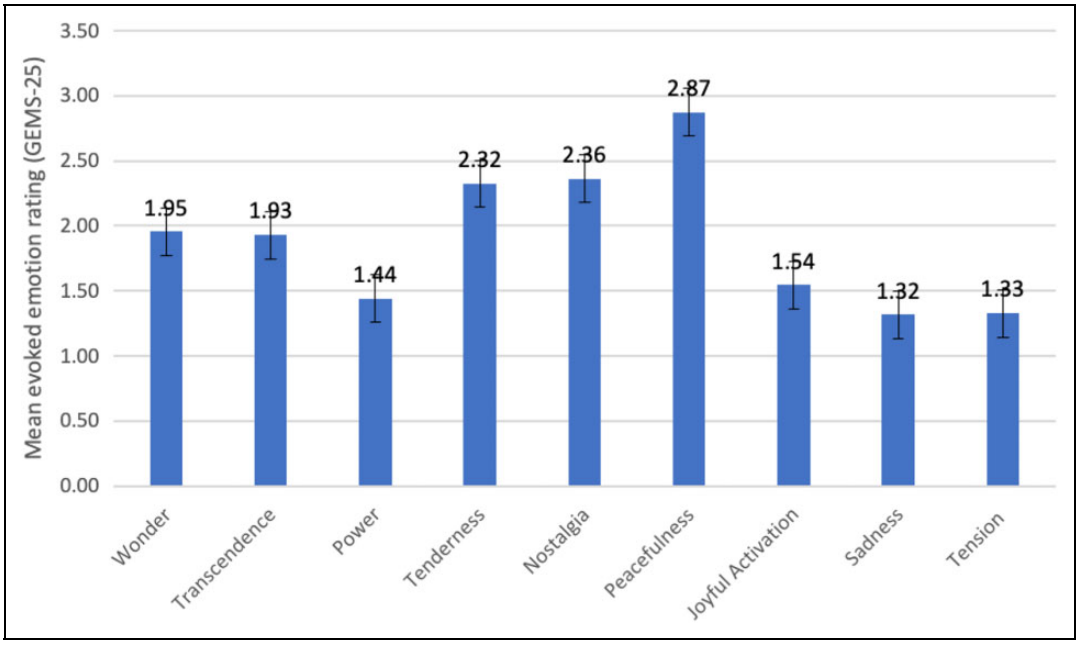

Figure 3. Mean scores for evoked emotions from Prelude.

Table 3. Mood states as predictors for clinical status.

	b	*SE*	*t*	p_t	*F*	p_F
Criterium: Clinical status						
Intercept	0.04	0.24	0.16	.871		
Age	0.00	0.00	0.71	.477		
Sex	0.12	0.10	1.21	.231		
POMS-A Anger	−0.02	0.02	−0.75	.457		
POMS-A Confusion	0.01	0.03	0.50	.618		
POMS-A Depression	0.01	0.03	0.16	.876		
POMS-A Fatigue	0.02	0.02	0.98	.330		
POMS-A Tension	−0.06	0.03	−2.09	.040		
POMS-A Vigor	−0.01	0.02	−0.59	.555		
R^2	0.12				1.53	.157

Note: $N = 98$.
POMS-A: Profile of Mood States–Adolescents.

Hartling et al., 2013; Johnson et al., 2012; Knight & Rickard, 2001; Nilsson, 2009; Piskorz & Czub, 2018; Plante et al., 2006; Reychler et al., 2015; Rothbaum et al., 2001; Taneja et al., 2017; Tarrant et al., 2018; Thoma et al., 2013). Our findings also extend prior research which shows that low arousal and high depth music features can decrease perception of pain in experimental tasks (Basinski et al., 2018). Taken together, this sets the stage for the future application and use of VR headsets which are an extension of the same technology we used in the present study.

Our preliminary research has potential use in varied settings. Given prior research that soothing music can increase recovery rates (Hole et al., 2015), spatial-audio applications might further accomplish this function, particularly given the loud, busy, and stressful surroundings that patients are accustomed to hospital environments. Examining an increase of recovery rates through the specific use of spatial audio experiences would be an interesting prospect for future research. Spatial-audio applications could also be used in education settings by teachers or school psychologists to help students in times of stress or misbehavior. Notably, our study found that participants enjoyed the musical elements significantly more than the visual elements. This raises questions about the incremental benefit of the virtual 3D environment and potential individual differences markers that distinguish preferences for audio and visual features.

This pilot had several limitations. First, the stress, mood, and evoked emotion metrics were gained through self-report assessments and a clinical diagnostic checklist. These results can be validated in future research using physiological and behavioral metrics. Second, our findings are based on an adult population that may be skewed toward being musical (as 68% of participants reported they have experience of playing a musical instrument). Future studies need to replicate the findings in populations that do not have this prior musical experience, and in populations that differ by age to see if such results can generalize to children and adolescents. Third, because the sample size was 100, only depression and anxiety disorders were measured. Future research should examine the effect of spatial-audio on other diagnoses including Attention Deficit Hyperactivity Disorder (ADHD) and autism. Fourth, stress and mood levels were only measured immediately after participation in Prelude, therefore, the effects can only be applied to the short term. Therefore, future research should measure temporal effects. Fifth, we only measured anxiety and mood states at baseline and did not measure more stable traits like personality, which may mediate or

moderate the effects. Sixth, the study advertisement, which described a study about stress reduction, may have been more appealing to those with a prior history of anxiety and depression and perhaps, as a result, we observed higher prevalence of anxiety and depression in our sample than that which is typically reported in the general population. In addition, based on the comorbidities and small sample size we observed during the initial screening and analyses, we decided to merge the anxiety and depression groups into a single group. Since this was not part of the initial design, it highlights a limitation in our methodological approach, namely that this was not a randomized control trial (RCT). Seventh, we did not compare Prelude with audio-only or video-only alternatives. Though we found a larger effect for preferences for the combined experience compared to the audio- and video-related measures alone, it would be sensible to compare Prelude to audio-only and video-only alternatives in future research.

There are two main implications for practice. First, board-certified clinical music therapists can give Prelude or a similar evidence-based program to clients to use as a supplement between therapy sessions. We would not advise that Prelude or other web-based audio applications programs to be used as an alternative, replacement, or substitute for face-to-face music therapy, particularly given the importance of the therapeutic relationship and its impact on treatment outcomes (Mössler et al., 2019). Prelude may also have an extended use as a supplement between sessions in clinical psychotherapy. Second, Prelude may be very beneficial within the field of music and medicine, and particularly in hospital settings. For example, given prior evidence on the effectiveness of music listening to reduce anxiety before and after surgeries and boost recovery (Hole et al., 2015), medical doctors can have patients use the Prelude platform and other evidence-based applications to relieve pre- and post-operative stress.

Given the exploratory nature of this work, we acknowledge that future research would benefit from patient and public involvement (PPI), where in-depth discussions and qualitative inquiries are used to assess the subjective experience of potential participants and the populations that are targeted for research. This will expand and improve the types of research questions that are asked and the ways in which this technology is applied in clinical, medical, and general-use settings.

In conclusion, we want to be clear that our findings provide no evidence that immersive spatial audio applications are preferable to or more effective than clinical music therapy. The client–therapist relationship and in-person musical interactions are paramount (Mössler et al., 2017), and web-based audio applications are not a replacement or substitute for clinical music therapies. However, certain settings (e.g., hospitals and nursing homes) may not have the necessary funds to hire a proportionate number of music therapists for the populations they serve. Therefore, immersive spatial audio is a promising *supplement* when a clinical music therapist is not available.

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Contributorship

DMG designed the research; DMG and KRF collected the data; DMG and KRF performed the analysis; DMG, EB, AS, and KRF wrote the paper.

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Notes

1. Music therapy is the "clinical and evidence-based use of music interventions to accomplish individualized goals within a therapeutic relationship by a credentialed professional who has completed an approved music therapy program" (https://www.musictherapy.org/about/quotes/). Music therapy is further defined as "reflexive process wherein the therapist helps the client to optimize the client's health, using various facets of music experience and the relationships formed through them as the impetus for change" (Bruscia, 2014). It can involve both joint music-making or music listening by the therapist and client, and can occur in both one-on-one ad group settings.
2. Music and medicine is a clinical and research area that describes the application and science of clinical music strategies in medicine (https://us.sagepub.com/en-us/nam/node/7006/print).

Supplemental Material

Supplemental material for this article is available online.

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